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Using Proximal Hooks as a Soft-Landing Strategy to Prevent Proximal Junctional Kyphosis in the Surgical Treatment of Scheuermann's Kyphosis

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ABSTRACT

AIM: To evaluate the occurrence of proximal junctional kyphosis (PJK) as well as both the clinical and radiologic outcomes of patients who underwent surgery for Scheuermann's Kyphosis (SK) using either exclusively pedicle screws or a combination of proximal hooks and pedicle screws constructs.

MATERIAL and METHODS: Surgically treated 37 patients with the diagnosis of SK were evaluated retrospectively. The patients were divided into two groups based on the type of instrumentation employed. The first group contained 22 patients with only pedicle screws (PP) while the second group consisted of 15 patients with mixed constructs that were proximal hooks and pedicle screws (HP) at the rest of the levels. The clinical and radiological data were compared in patients who were followed up for a minimum of 2 years.

RESULTS: The average duration of follow-up for the PP group was approximately 94.7 ± 53.1 months, whereas the HP group had an average follow-up period of around 103 ± 64.4 months. After conducting the analyses, no statistically significant findings were identified in the measurements taken for the SRS-22 scores in preoperative, postoperative, and the most recent follow-up radiographs ($p>0.05$). It is worth noting that among patients who exclusively utilized pedicle screws, both the proximal ($p=0.045$) and distal ($p=0.030$) junctional kyphosis angles experienced more pronounced increases compared to hybrid structures.

CONCLUSION: While no notable distinction was observed between the two groups, patients with pedicle screws fixation had a higher PJK angle. Conversely, the use of hooks at the upper end seems to be a preventive measure against the development of PJK.

KEYWORDS: Scheuermann's kyphosis, Proximal junctional kyphosis, Hook fixation, Pedicle screw

INTRODUCTION

In Scheuermann's disease, due to chronic back pain with kyphotic deformity of the spine of 70 degrees and above, cosmetic issues and neurological problems depending upon advanced kyphotic deformity, surgical treatment can be applied (3,4,27,37). Successful correction can be achieved with surgical interventions through combined anterior posterior or posterior only approaches. In recent years, the posterior approach has been preferred more by spine surgeons due to less blood loss and shorter operative duration (19,20). In posterior interventions, proximal junction kyphosis (PJK) is seen due to some preoperative factors. Kim and Lyer (16) defined PJK when the Cobb angle between the lower endplate of the upper instrumented vertebra (UIV) and

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the upper endplate of the upper instrumented vertebra (UEV) + 2 upper vertebrae is greater than 10 degrees (16). In the literature, PJK has been reported at a rate of approximately 10-30% after Scheuermann's Kyphosis (SK) surgeries (8,9).

Although PJK is not always symptomatic after surgery, approximately 10% of PJK patients require revision surgery because of proximal junction failure (PJF) (15,38). PJF is more common in adults after spinal surgery than in children and is defined as chronic pain in the proximal junction segment, implant failure in the upper instrumented vertebra, adjacent segment vertebral fracture, and neurological problems due to excessive kyphosis (35,36).

It has been reported that after SK surgery, PJK occurs due to factors such as the correction of kyphosis more than 50%, inadequate fusion levels, and failure to preserve the integrity of the posterior ligamentous complex and facet joint at the cranial end (1,2,14,28). Among the stabilization methods used in posterior spine surgery (hooks, sublaminar bands and pedicle screws), there are heterogeneous reports in the literature regarding the PJK, and studies at the high-level of evidence reporting the superiority of any technique are still insufficient (34). Especially, there are a few studies available in the literature regarding the usage of hooks only at the most proximal end of the construct as a soft-landing procedure.

Our hypothesis was that the use of hooks in the fixation of the most proximal end level can prevent the PJK. Thus, the aim was to evaluate surgically treated SK patients with only pedicle screws and pedicle screws together with hooks in the proximal end regarding the postoperative PJK by utilizing radiological and clinical parameters.

MATERIAL and METHODS

This study was performed in line with the principles of the Declaration of Helsinki. The study has been approved by Gazi University Clinical Research Ethics Committee (Date: 26.09.2022 / Number: 020).

Patients who were operated on with the diagnosis of SK in the Department of Orthopedics and Traumatology of our institution between January 2005 and December 2019 were retrospectively scanned. This study was conducted with thirty-seven patients for whom only pedicle screws were used with the posterior approach and fusion was performed by using pedicle screws and proximal hooks at the most cranial segment. Inclusion criteria were having clinical and radiological follow-up for at least 24 months, not having a previous spine surgery, and having surgery with a posterior approach only. Thirty-seven patients who matched the criteria and were between the ages of 15 and 30 were included in this study. Patients with congenital or additional diseases, constructs including multiple levels of the hooks, and patients who underwent surgery with an anterior or anterior-posterior combined approach were excluded from the study.

Thirty-seven patients were divided into two groups according to the type of instrumentation used. The first group included 22 patients who were instrumented by using only pedicle screws (PP) at every level, and the second group included 15 patients who underwent hooks fixation (HP) in the UIV and pedicle screws at the rest of the segments. Preoperative and immediate postoperative standing radiographs, final follow-up radiographs, and Scoliosis Research Society 22 (SRS-22) scores of all patients were evaluated. In the radiological evaluations of the patients, preoperative thoracic kyphosis (between T2 and T12), lumbar lordosis (between L1 and S1) Cobb angles, and the C7-sagittal vertical axis (C7-SVA) values were determined. Early postoperative (at the 6th week after surgery) and at the last follow-up thoracic kyphosis angle, proximal junction angle (PJA), distal junction angle, and C7-SVA were measured (Figure 1, 2). Also, the study involved the measurement of lumbar lordosis, pelvic tilt, sacral slope, and pelvic incidence (PI) angles in all patients (Figure 3). The patients were subsequently categorized according to the Roussouly classification system. This classification system is a commonly used method for characterizing the sagittal alignment of the spine (30).

Surgical Technique

Surgery was performed by a senior single spine surgeon. After general anaesthesia was applied to the patients, thoracic/thoracolumbar lateral radiographs were taken under traction in the supine position. The fusion levels of the spine were evaluated one more time, along with the traction radiographs and other standing and bending radiographs. The patient was then turned to the prone position. Silicone pads were placed on the appropriate body parts of the patient both to prevent pressure sores and bleeding. A long incision was made from the posterior midline following the sterile covering of the surgical field and folds passed. The paraspinal muscles were dissected subperiosteally while preserving the supraspinous and interspinous ligaments. During the opening of the upper and lower vertebrae to be included in the fusion, meticulous dissection was made to preserve the posterior ligamentous structures and facet joint to avoid adjacent segment failure. After exposing the area to be instrumented, pedicle screws were placed while in some patients, transverse process down-going hooks were inserted bilaterally into the UIV. Screws were placed using free hand technique. Then 6.5 mm screws were placed in the lumbar and lower thoracic region, and 5.5 mm screws were placed in the middle thoracic and upper thoracic regions. The suitability of the screw locations was evaluated by taking X-rays during the operation. In all patients, Schwab 2 osteotomy was applied to the apex region of the kyphosis between 3 to 5 levels depending on the amount of correction, and Schwab 1 osteotomy was applied to the other segments according to the stiffness of the curvature (10,31). Then, the rods were placed by providing correction of kyphosis via the cantilever technique (32). During the cantilever manoeuvre a technician applied traction from the head to decrease the pull-out stress of the pedicle screws. After some compression was applied to the apex region of the kyphosis, the crown screws were tightened. All these processes were performed under multimodal intraoperative neuromonitoring (33). The patients were mobilized on the first postoperative day without a brace.

In our clinic, as the lowest instrumented vertebra (LIV) level, we prefer the sagittal stable vertebra recommended by Cho et

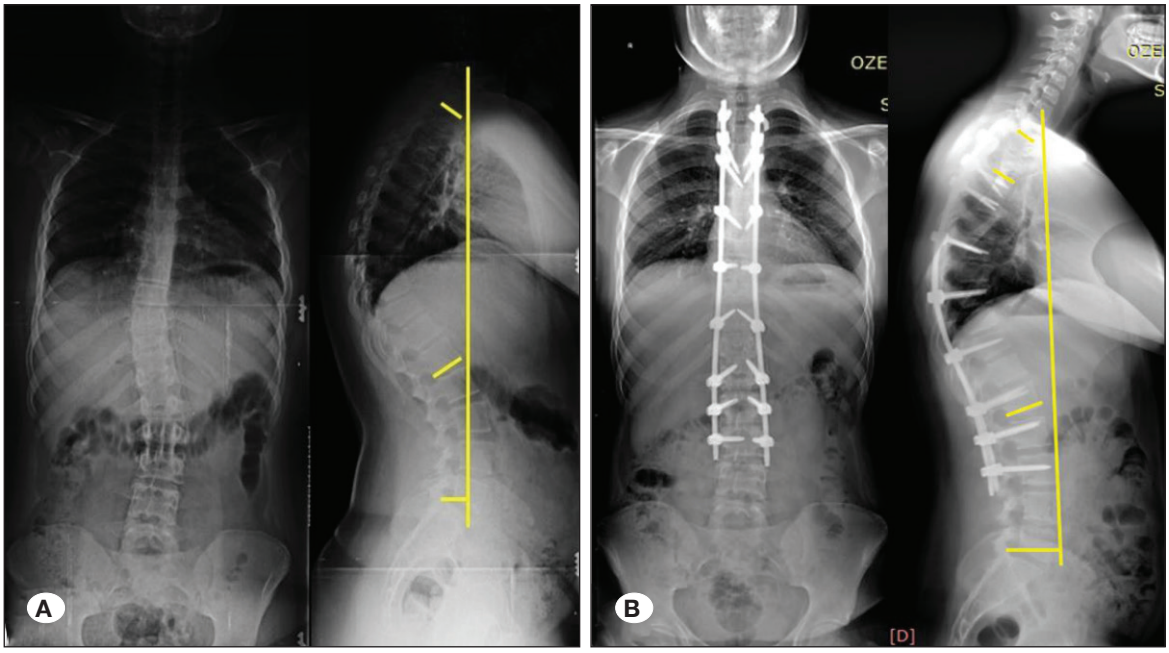

Figure 1: Radiological evaluation of patients with mixed constructs that is proximal hooks and pedicle screws at the rest of the levels (HP group) [**A)** preoperative; **B)** postoperative].

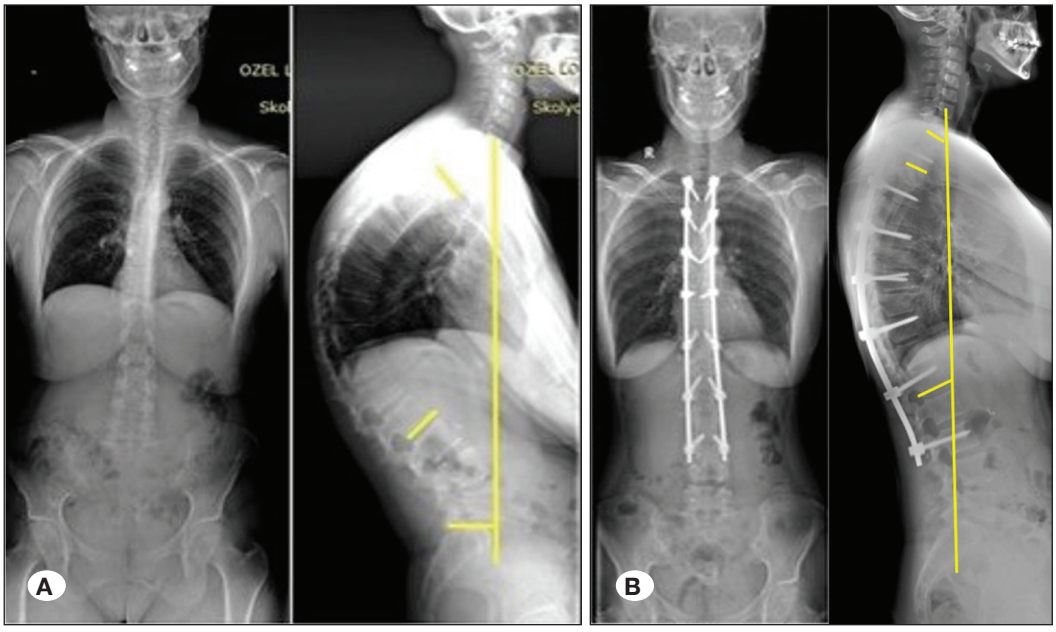

Figure 2: Radiological evaluation of patients who were instrumented by using only pedicle screws. (PP group) (**A:** preoperative; **B:** postoperative).

al. (7). We prefer the T2 or T3 level as UIV level. The important thing is to avoid the apex of the proximal thoracic kyphosis in the sagittal plane.

As for the choice of hook or pedicle screw at the proximal level, in previous years we usually used hooks at the most proximal level. For the last 10 years, we have been placing pedicle screws at the upper level. This change in preference is based on our belief that careful preoperative planning and vigilant execution during surgery can significantly reduce the incidence of PJK.

Statistical Analysis

IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA) was used for statistical analysis, and a p-value of 0.05 was considered statistically significant. Continuous variables are presented as mean standard deviation, while categorical variables are presented as numbers and percentages (SD). To compare categorical variables, Chi-square tests were used. The conformity of continuous variables to the normal distribution was assessed visually (histograms and probability graphs) and analytically (Kolmogorov-Smirnov and Shapiro-Wilk tests). To compare data in accordance

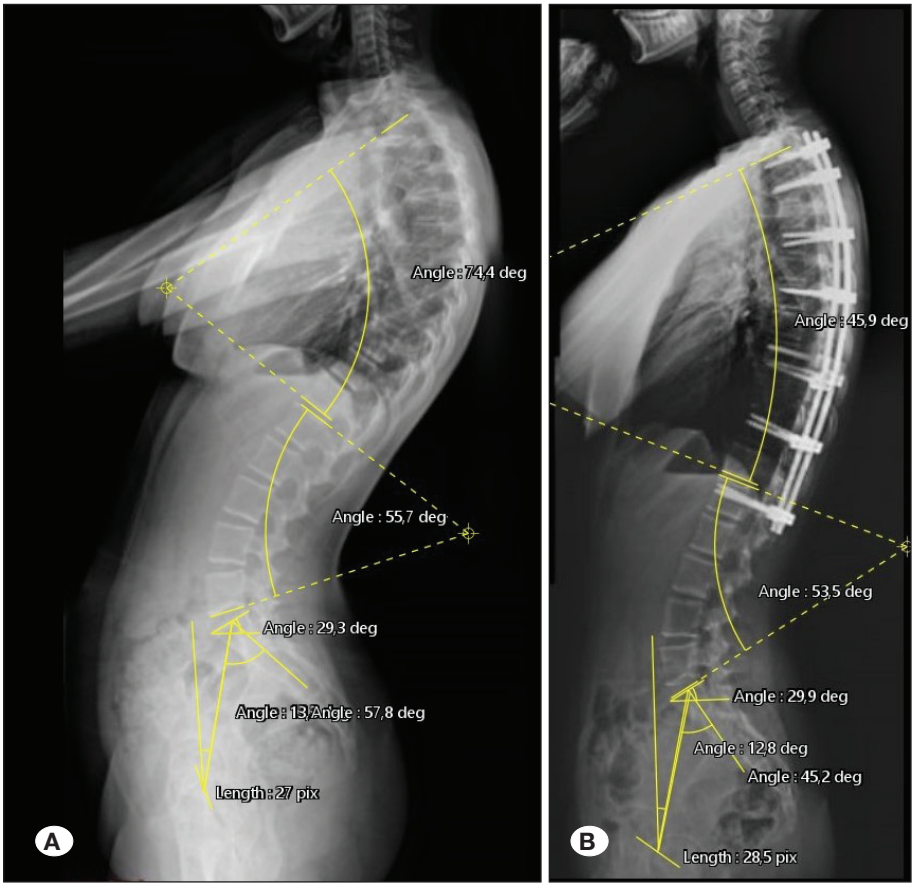

Figure 2: Radiological evaluations of spinopelvic parameters. (**A:** preoperative; **B:** postoperative).

with normality testing, the independent samples t-test and the Mann-Whitney U test were used.

RESULTS

There was a total of 22 patients including 14 males and 8 females in PP group, and a total of 15 patients including 8 males and 7 females in HP group. The mean age of the patients was 26.58 ± 7.55 years in PP group, and 25.46 ± 9.04 years in HP group. Mean follow-up times were 94.73 ± 53.15 months in PP group, and 103.07±64.48 months in HP group (Table I).

The analysis of SRS-22 questionnaire data indicated that the total scores and domain scores were similar in both groups. No statistically significant differences were observed between the groups, as indicated by the p values (p=0.106; 0.092; 0.354; 0.115; 0.904; 0.137) (Table II).

When the radiological evaluation results were taken into consideration, the preoperative kyphosis angles (PP: 76.55±6.420; HP: 74.87 ± 7.820) (p=0.479) had similar radiological values in the early postoperative period in both groups (PP: 47.59 ± 6.430; HP: 48.26 ± 5.680) (p=0.744). Moreover, the values were close in the last follow-ups, too (PP:52.81 ± 6.67^0; HP: 51.00 ± 6.71^0) (p=0.422) (Table III).

Examination of the C7-SVA measurements revealed that the results of the two groups were similar in the preoperative period (PP: -18.86 ± 41 mm.72; HP: -6.20 ± 40.14 mm) (p=0.364), early postoperative period (PP: -15.00 ± 34.09 mm; HP: -4.00 ± 31.80 mm) (p= 0.329), and final control radiographs (PP: -21.09 ± 27.02 mm; HP: -16.00 ± 33.50 mm) (p=0.613) (Table III).

As a result of radiological evaluation, 4 (18.1%) patients in PP group and 3 (20%) patients in HP group had an increase in the PJK angle (Table I). The average of PJK angle was 7.50 ± 10.13 degrees in PP group and an average of 10.13 ± 5.89 degrees in HP group in the early postoperative period (p=0.150), while an increase was observed in PP group to an average of 14.18 ± 12.88 degrees and in HP group to an average of 13.53 ± 7.66 degrees at the final follow-ups and showed no significant difference between the two groups (p=0.862). However, the mean increase in PJK at early and final follow-ups were 7.72±8.41 degrees in PP group and 3.40 ± 5.97 degrees in HP group, and there was a significant difference between the two groups (p=0.045) (Table III).

When distal junction angles were examined, the early postoperative values were very close to each other in the two groups (mean PP: -3.23 ± 6.52°; HP: -3.80 ± 3.93°) (p=0.763). There was no significant difference between the two groups in the final control values (PP: -1.55 ± 9.840; HP: -6.00 ± 4.860) (p=0.078). However, the mean values of distal junctional angle (DJA) at early and final follow-ups were 1.16 ± 7.30 degrees in PP group and -2.20 ± 2.68 degrees in HP group, and there

Table I: Demographic Characteristics and Basic Information of the Patients

	PP group	HP group	p-value
Gender (M/F)	14/8	8/7	0.386
Mean age ± SD (age)	26.58 ± 7.55	25.46 ± 9.04	0.705
Follow-up ± SD (month)	94.73 ± 53.15	103.07 ± 64.48	0.670
PJK (n)	4	3	0.606

M: *Male;* ***F:*** *Female;* ***SD:*** *Standard deviation;* ***PJK:*** *Proximal junctional kyphosis.*

Table II: The Results of the Statistical Analysis that Belong to SRS-22 Questionnaire

	PP group	HP group	p-value
SRS-22 total score	4.11 ± 0.34	3.89 ± 0.56	0.106
SRS-22 pain	4.26 ± 0.46	3.96 ± 0.60	0.092
SRS-22 function	4.34 ± 0.49	4.16 ± 0.71	0.354
SRS-22 self-image/appearance	4.16 ± 0.74	3.74 ± 0.81	0.115
SRS-22 mental health	3.49 ± 0.51	3.46 ± 0.71	0.904
SRS-22 satisfaction	4.59 ± 0.70	4.23 ± 0.70	0.137

PP group: *Only pedicle screw group,* ***HP group:*** *Proximal hooks and pedicle screws at the rest of the levels group,* ***SRS-22:*** *Scoliosis Research Society-22 questionnaire.*

Table III: The Results of Statistical Analysis that Belong to Radiological Evaluation Data

	PP group	HP group	p-value
Preop kyphosis angle	76.55 ± 6.42	74.87 ± 7.82	0.479
Preop C7-SVA	-18.86 ± 41.72	-6.20 ± 40.14	0.364
Early postop kyphosis angle	47.59 ± 6.43	48.26 ± 5.68	0.744
Early postop C7-SVA	-15.00 ± 34.09	-4.00 ± 31.80	0.329
Early postop PJA*	7.50 ± 10.13	10.13 ± 5.89	0.150
Early postop DJA*	-3.23 ± 6.52	-3.80 ± 3.93	0.763
Last follow-up kyphosis angle	52.81 ± 6.67	51.00 ± 6.71	0.422
Last follow-up C7-SVA	-21.09 ± 27.02	-16.00 ± 33.50	0.613
Last follow-up PJA*	14.18 ± 12.88	13.53 ± 7.66	0.862
Last follow-up DJA*	-1.55 ± 9.84	-6.00 ± 4.86	0.078
Mean difference of kyphosis angle (Postop - Preop)	47.59 ± 6.43	48.27 ± 5.68	0.744
Mean difference of kyphosis angle (Last follow-up - Postop)	5.23 ± 4.14	2.73 ± 3.31	0.060
Mean difference of PJA*	7.72 ± 8.41	3.40 ± 5.97	**0.045**
Mean difference of DJA*	1.16 ± 7.30	-2.20 ± 2.68	**0.030**

SVA: *Sagittal vertical axis,* ***PJA:*** *Proximal junctional angle,* ***DJA:*** *Distal junctional angle.* ****** *Lordosis represented as negative values; kyphosis represented as positive values.*

was a statistically significant difference between the two groups (p=0.030) (Table III).

The results of sagittal spinopelvic parameters showed that the mean lumbar lordosis angles in both groups were greater than the normal values (PP: 66.82° ± 11.05; HP: 65.80° ± 8.71). Early postoperative (PP: 54.27° ± 5.46; HP: 50.13° ± 5.93) and final control radiographs (PP: 55.27° ± 4.54; HP: 51.73° ± 4.67) showed the restoration of lumbar lordosis angles within normal ranges (Table IV). PI values were stable because the patients were generally in late adolescence and adult patients. In the sacral slope values, preoperative values were higher in HP group than in PP group (PP: 36.55° ± 8.48; HP: 39.07° ± 5.15), whereas there was a greater decrease in HP group in the early postoperative (PP: 34.77° ± 5.43; HP: 30.20° ± 4.41) and final control (PP: 35.73° ± 5.76; HP: 31.27° ± 8.26) radiographs. However, there was no statistically significant difference between the two groups (p=0.061) (Table IV). According to Roussouly's classification, 1 patient (4.5%) was type 1, 5 patients (22.7%) were type 2, 14 patients (63.6%) were type 3, and 2 patients (9%) were type 4 in PP group preoperatively. In HP group, there were no patients with Roussouly type 1, 3 patients (20%) had type 2, 10 patients (66.6%) were type 3 and 2 patients (13%) had type 4 values. Postoperatively, the classification according to Roussouly changed as thoracic kyphosis, lumbar lordosis and sacral slope angles changed. The majority of patients had Roussouly type 2 values (Table IV).

DISCUSSION

In the current study, of the use of proximal down-going transverse process hooks as a soft-landing procedure was studied with radiological and clinical parameters including X-Ray measurements and SRS-22 questionnaire conduction.

There are many etiological reasons for the PJK after SK surgery. Of these, overcorrection can cause sagittal malalignment as well as proximal and distal junction problems. Lowe and Kasten reported that 50% or more corrections might cause sagittal balance disruption and PJK (25). In our study, approximately 38% improvement was achieved in the thoracic/thoracolumbar kyphosis angle (from 76.55 ± 6.42 degrees to 47.59 ± 6.43 degrees in PP group, and from 74.87 ± 7.82 degrees to 48.26 ± 5.68 degrees in HP group) (Table III). We evaluated all our SK patients with preoperative hyperextension radiographs and/or preoperative lateral traction X-ray after general anaesthesia induction. In cases where the kyphosis did not improve sufficiently on hyperextension and traction radiographs (if the kyphosis angle did not decrease below 50^0), multiple Schwab Type-2 osteotomy were performed (32, 33) to the apical segments.

Table IV: Statistical Analysis Results of Spinopelvic Parameters in Radiological Evaluation

	PP group	HP group	p-value
Preoperative			
Lumbar Lordosis	66.82° ± 11.05	65.80° ± 8.71	0.767
Pelvic Incidence	47.77° ± 5.85	46.60° ± 4.94	0.529
Sacral Slope	36.55° ± 8.48	39.07° ± 5.15	0.312
Pelvic Tilt	12.27° ± 6.69	8.27° ± 4.43	**0.035**
Roussouly Classification (1/2/3/4)	1/5/14/2	0/3/10/2	0.832
Early Postoperative			
Lumbar Lordosis	54.27° ± 5.46	50.13° ± 5.93	**0.035**
Pelvic Incidence	47.91° ± 5.64	46.60° ± 4.78	0.467
Sacral Slope	34.77° ± 5.43	30.20° ± 4.41	**0.010**
Pelvic Tilt	13.95° ± 3.97	16.40° ± 3.25	**0.048**
Roussouly Classification (1/2/3/4)	2/7/12/1	2/11/2/0	**0.046**
Last Follow-up			
Lumbar Lordosis	55.27° ± 4.54	51.73° ± 4.67	**0.027**
Pelvic Incidence	47.82° ± 5.78	46.80° ± 4.96	0.571
Sacral Slope	35.73° ± 5.76	31.27° ± 8.26	0.061
Pelvic Tilt	12.82° ± 4.56	12.60° ± 3.79	0.880
Roussouly Classification (1/2/3/4)	2/6/13/1	1/5/9/0	0.836

PJK usually develops after posterior spinal fusion surgery (23,22). Symptomatic PJK usually develops due to proximal soft tissue insufficiency, implant dislocation or loosening, and fracture of the proximal spine. Due to these reasons, patients may develop pain, serious cosmetic deformities, and neurological deficits (6,11). We believe that using hooks at the upper end allows us better protection of midline structures and bilateral facet capsules at the most cranial transitional zone.

It has been shown in previous studies that pedicle screws are mechanically superior to hooks in three-dimensional correction of spinal deformity (17,39). In terms of PJK, although there are studies reporting that there is no significant difference in terms of PJK between patients with pedicle screws and hooks instrumentation (21), there are many studies which show that the incidence of PJK is lower in patients with proximal hooks (12,13).

In our study, it was observed that the PJK angles were higher in patients who had only pedicle screws applied than in patients who had a hybrid fixation with proximal hooks. There was no significant difference between the two groups in early and final control PJK values (early: p=0.150; last follow-up: p=0.862, respectively) (Table III). However, the amount of increase in PJK at early and final control was higher in PP group and there was a statistically significant difference between the two groups (p=0.045) (Table III).

The occurrence of PJK varies considerably, with reported rates ranging from 5% to 46% who have undergone spinal instrumentation and fusion for spinal deformities. Furthermore, the reported rates of revisions attributed to PJK span from 13% to 55% (18,29). The study conducted by Matsumura et al. (26) aimed to compare the effectiveness of hooks and pedicle screws as instruments of spinal fixation in adult patients undergoing spinal deformity surgery. A total of 17 patients received hooks and 22 patients received pedicle screws with a mean follow-up duration of 41 months. The results indicated a higher mean proximal junctional angle (PJA) in the pedicle screw group (19° degrees) compared to the hook group (5° degrees). Additionally, the incidence of proximal junctional kyphosis was reported as 17.6% in the hook group and 27.3% in the pedicle screw group (26). In the current study, PJK was seen at 20% in HP group and 18.1% in PP group, and we observed an average increase of 7.7 (from 7.50 to 14.18) degrees in the PJK angle between the early postoperative period and the final control in PP group, while an increase of 3.4 (from 10.13 to 13.53) degrees was observed in HP group. PJK angles were 14.18 degrees in PP group and 13.53 degrees in HP group at the last follow-up radiographs. Although there was no significant difference between the two groups in PJK angles at the last follow-up radiographs, there was a significant increase in PJK angle in PP group at the follow-ups (Table III).

In addition, C7-SVA values were negative in both groups, too. While in preoperative (PP/HP: -8.86 ± 41.72 mm/-6.20 ± 40.14 mm) and early postoperative period (PP/HP: -15.00 ± 34.09 mm/-4.00 ± 31.80 mm) an improvement was observed in both groups on average of 28% (PP/HP: 20.4%/35.4%), in the last control although there was an increase in both groups, it was more in HP group. Finally, there was no significant difference between the two groups (p=0.364; 0.329; 0.613) (Table III).

Distal junctional kyphosis (DJK) after posterior fusion surgery has been reported with a rate of 13-38% (24). DJK develops due to inappropriate choice of the lower instrumented vertebral level and the amount of correction of the spinal deformity (23,24,40). Therefore, the choice of the lowest instrumented vertebra (LIV) is also important in SK surgery. Cho et al. defined the sagittal stable vertebra as the LIV and proposed the inclusion of the stable sagittal vertebra in the fusion site (7). Successful results have been reported in the selection of the stable sagittal vertebra as the lowest instrumented vertebra to prevent DJK (23,24,40). In our study, we used the same technique for the selection of the LIV after the sagittal stable vertebra concept was described. Before this concept, we used the first lordotic segment for the LIV. There was no significant difference between the two groups in terms of DJK at early and final follow-up (early: p=0.763; last follow-up: p=0.078, respectively) (Table III). However, the amount of increase in DJK was higher in PP group in the early and final control, and there was a statistically significant difference between the two groups (p=0.030) (Table III).

Although there was a significant increase in PJK and DJK in PP group in early and last control radiographs, there was no significant difference between the two groups in total and subgroup scores according to the SRS -22 questionnaire (Table II).

The PI angle is the sum of the pelvic tilt and sacral slope angle and has a fixed angle in adults. Buyuk et al. reported that the incidence of PJK in spinal deformity surgery was 4.9 times higher in patients with high PI (>50°) than in those with low PI (<50°) (5). In our study, we found that the mean PI values were below 50° in PP and HP groups, and the PI values did not change in the early and final postoperative controls (Table IV).

In addition, Buyuk et al. reported that in Roussouly type 3 and 4 patients with high sacral slope and in patients with excessive lumbar lordosis restoration, the risk of PJK may increase by causing uncontrolled thoracic kyphosis compensation (5). In our study, when we evaluated the patients according to the Roussouly classification, it was observed that there were changes in Roussouly types due to changes in sagittal spinopelvic parameters in patients before and after surgery. The total number of patients with Roussouly types 3 and 4 at the last follow-up was 14 (64%) in PP group and 9 (60%) in HP group, and no significant difference was observed between the two groups (Table IV). When we evaluated the restoration of lumbar lordosis in our study, middle and lower lumbar spines were not included in the fusion in any patient. While the mean preoperative lumbar lordosis values were above 60° in both groups, they were below 60° in the postoperative early control (PP: 54.27° ± 5.46; HP: 50.13° ± 5.93) and final controls (PP: 55.27° ± 4.54; HH: 51.73° ± 4.67) (Table IV). Considering the PI values, it is seen that an appropriate degree of lumbar lordosis restoration was achieved.

The most important limitations of the current study were the retrospective design and the relatively limited sample size. In addition, another limitation was that the SRS 22 questionnaire was not applied to the patients before surgery.

CONCLUSION

Even though there was not a notable distinction between the two groups, it was observed that the PJK angle was greater in patients who had undergone pedicle screws fixation. Consequently, it is essential to closely monitor the occurrence of PJK when employing pedicle screws fixation at the uppermost spinal segment. Furthermore, the use of transverse process hooks in the uppermost segment appears to offer a more effective safeguard for soft tissues, including the posterior ligamentous complex and facet capsules, potentially reducing the risk of PJK.

AUTHORSHIP CONTRIBUTION

Study conception and design: ACB, MAT, ID, AS
Data collection: MAT, ID, YOA
Analysis and interpretation of results: MAT
Draft manuscript preparation: ACB, AY, MAT, ID, YOA, AS
Critical revision of the article: ACB, MAT, ID, YOA, AS
Other (study supervision, fundings, materials, etc...): YOA, AS
All authors (ACB, AY, MAT, ID, YOA, AS) reviewed the results and approved the final version of the manuscript.

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